International Journal of Engineering Research (ISSN : 2319-6890)
Volume No.2, Issue No. 3, pp : 259-265 01 July 2013

A Framework for Quantification of Effect of Drainage Quality on Structural and Functional Performance of Pavement

Jitendra Gurjar, Pradeep Kumar Agarwal, Manoj Kumar Sharma

[1,2]Deptt. of Civil Engineering Maulana Azad National Institute of Technology, Bhopal -462051 (MP), India
[3]MP State Employment Guarantee Council, Bhopal -462051(MP), India
Email jiten.manit@gmail.com Email pka9@yahoo.com Email mksbpl@dataone.in

Abstract:

Drainage quality is an important parameter which affects the highway pavement performance. Excessive water content in the pavement base, sub-base, and sub-grade soils can cause early distress and lead to a structural or functional failure of pavement. Thus, when selecting appropriate maintenance strategies the cost of pavement maintenance needs to be compared with the cost of improving the quality of drainage. Hence, there is a need to quantify the effect of various types of drainage quality on performance of the pavement. However, very few studies have investigated to what extent quality of drainage affects the performance of pavement. Therefore, this study identifies a simple framework for quantification of effect of drainage quality on structural as well as functional performance of the pavement. The proposed framework presents the structural and functional performance of the pavement is predicted in terms of deflection and roughness respectively. It is expected that this study will useful to reduce the maintenance cost of highway pavement system and hence will be useful to preserve huge highway network in India.

Key Words: Pavement Performance, Modified structural Number, Drainage Quality,

1 Introduction

It is a well-known fact that water in pavement systems is one of the principal causes of premature pavement failure. Indian road network at over 3.3 million km falls under one of the world's longest road networks. Most of the highways and airfield pavements built in our country in the past 30 years or so, have very slow draining systems, largely because standard design practices emphasizes on density and stability but place little importance on drainage. Drainage is a key element in the design of pavement systems. However, inadequate drainage continues to be identified as a major cause of pavement distress. Water is a leading factor in causing damage to pavements. Extensive field tests and observations have indicated that rates of damage and loss in serviceability of both rigid and flexible types of pavements are much greater when structural section contain free water. Quality of drainage is an important parameter which affects the performance of the highway pavement. The poor drainage quality on these roads leads to large amount of costly repairs or replacements long before reaching their design life. Not much importance has been given to this aspect in India. However, the gradation and properties of layer materials seldom permit the layer to be an effective drainage layer, leading to entrapment of water within the pavement causing a "bathtub" condition, resulting in premature failures and chronic pavement distresses. Hence, there is a need to quantify the impact of quality of drainage on pavement performance. However, very few studies have investigated to what extent quality of drainage affects the performance of pavement. Therefore this study presents a framework for the quantification of effect of drainage quality on functional performance of the pavement as well as structural performance of the pavement. The functional performance and structural performance of the pavement is predicted in terms of roughness & deflection respectively.

The main objectives of this study are as follows:

- To present the need of the study of effect of drainage quality on performance of the pavement.
- To presents a framework for quantification of effect of drainage quality on structural performance of pavement
- To presents a framework to evaluate the effect of drainage quality on functional performance of pavement.

This paper consists of five chapters of which this is the first one. This section focuses on the basic issues due to poor drainage and objectives. The second section presents briefly overview of literature on previous work carried out on highway drainage. The third section briefly presents the effect of poor drainage on pavement performance and various pavement distresses due to poor drainage. The fourth sections briefly describe need of the study on effect of drainage quality on pavement performance. The section five presents a framework for quantification of effect of drainage quality on structural as well as functional performance of the pavement. The last sections presents the important conclusions drawn based on this study.

2 Literature Review

To meet the objective of this study, a literature available on highway drainage were reviewed. Literature reviews on highway drainage are briefly summarized as follows:

Rokade S, Et al (2012) "The drainage design criteria used in the past have been based on the assumption that both the flow of water through pavements and the drainage of pavement layers can be represented with saturated flow assumptions. The detrimental effects of water can be reduced by preventing water from entering the pavement, providing adequate drainage to remove infiltration, or building the pavement strong enough to resist the combined effect of load and water. Pavement service life can be increased by 50% if infiltrated water can be drained without delay. Similarly, pavement systems incorporating good drainage can be expected to have a design life of two to three times that of un-drained pavement sections"

Veeraragavan A. Et al (2010) carried out "sub surface drainage is a key element in the design of pavement system. An optimum performance of a pavement system can be achieved by preventing water entering by means of a well designed subsurface drainage system.

G. Shailendra et al (2010) carried out "Inadequate sub-surface drainage continues to be identified as a major cause of pavement distress. The entrapment of water within the pavement leads to a "bathtub" condition resulting in premature failures and chronic pavement distresses. This leads to large amount of costly repairs or replacement to the pavements long before they reach their design life. Hence there is need to carry out research work in India to demonstrate and quantify the impact of sub-surface drainage on pavement performance to reduce the future maintenance cost and preserve the road assets."

3 Effect of Poor Drainage on Pavement Performance

Excessive moisture within a pavement structure can adversely affect pavement performance. A Pavement can be stable at given moisture content, but may become unstable if the materials become saturated. High water pressures can develop in saturated soils when subjected to dynamic loading. Subsurface water can freeze, expand, and exert forces of considerable magnitude on a given pavement. Water in motion can transport soil particles and cause a number of different problems, including clogging of drains, eroding of embankments, and pumping of fines. These circumstances must be recognized and accounted for in the design of a pavement. The detrimental effects of water on the structural support of the pavement system are outlined by AASHTO (1993), as follows:

- Water in the asphalt surface can lead to moisture damage, modulus reduction, and loss of tensile strength. Saturation can reduce the dry modulus of the asphalt by as much as 30% or more.
- It reduces the strength of unbounded granular material and Sub-grade soils.
- Continues contact with water causes stripping of bituminous mixture
- Added moisture in unbound aggregate base and sub-base is anticipated to result in a loss of stiffness on the order of 50% or more.
- Modulus reduction of up to 30% can be expected for asphalt-treated base and increase erosion susceptibility of cement or lime treated bases.
- Saturated fine-grain roadbed soil could experience modulus reductions of more than 50%.
- Surface scour is the loss of surface material caused by the flow of water along and/or over the road. This often leads to considerable gravel loss as channels are cut into the road surface either laterally or down the grades. The problem is exacerbated if there is loose material on the surface, for example after a blading operation and before the surface is reconsolidated by traffic. The ability of the surface material to resist erosion depends on the shear strength under which the water flow occurs.
- Carpenter et al (1981) summarized moisture related bituminous concrete pavement distresses characterized by excessive deflection, cracking, reduced load bearing, raveling, and disintegration. Table 1 shows the moisture related distresses in flexible pavement.

4 Need of the study

The important of adequate and efficient drainage to the structural integrity of a road is well recognized. Water has a key role when discussing the mechanical performance and lifetime of any traffic infrastructure. The problems caused by an inadequate or poor drainage or lack of appropriate maintenance or defective drainage systems are aquaplaning, skidding on ice, Swerving to avoid standing water, flooding and damage to adjacent property and land, erosion and damage to the road structure requiring costly repairs, nuisance splashing of pedestrians. The fact, known for centuries, is that as long as road structures and sub-grade soil do not have excess water the road will work well. But increased water content reduces the bearing capacity of a soil, which will increase the rate of deterioration and shorten the lifetime of the road. In such cases, the road will need rehabilitation more often than a well-drained road structure. Thus, when selecting appropriate maintenance strategies the cost of pavement maintenance needs to be compared with the cost of improving the quality of drainage. Hence, there is a need to quantify the impact of quality of drainage on pavement performance and develop a simple methodology for evaluate the effect of drainage quality on pavement performance. However, very few studies have investigated to what extent quality of drainage affects the performance of pavement. We need to study of highway drainage system for some following reasons also:

- An increase in moisture content decrease in strength or stability of a soil mass.

- Surface water runoff to remove the water from areas of carriageway or footpath where its presence would be harmful or dangerous to users or lead to deterioration. The flowing water has capacity to damage the road while flowing down the shoulders and side slopes. in this process the water cause erosion and again deposits the material causing siltation at other point both requiring of measures to reduces the damage due to each.
- The water which entered into the pavement layers during rains from (a) loose soil fill in the median (b) shoulders and (c) pervious surface at some locations of the DBM layer could not drain out through the impervious GSB layer and thus the entrapped water level increased within the pavement, saturating the WMM and BM layers. Consequently, the BM layer and part of DBM layers got deteriorated and failed as a result of stripping and weakening of the bituminous mix.

5 A Framework for Quantification of Effect of Drainage Quality on Pavement Performance

As discussed earlier the main objective of this study is o present a framework for quantification of effect of drainage quality on structural as well as functional performance of pavement. The proposed framework presents the structural and functional performance of the pavement is predicted in terms of deflection and roughness respectively.

5.1 A Framework for Quantification of Effect of Drainage Quality on Structural Performance of Pavement

In many Developing Countries and particularly in India the pavement structural condition is defined in terms of the Benkelman Beam Deflection. In this study the Structural performance of the pavement is predicted in terms of Deflection. The proposed methodology for effect of drainage quality on pavement structural performance in terms of deflection presented in Fig. 1**.**

The following major steps involved in computation of structural performance of the pavement:-

Step I Estimation of Design Traffic in Cumulative Standard Axles

The following equation has been used for converting commercial vehicles per day (CVPD) in terms of Cumulative Number of Standard Axles as per the procedure laid down in IRC 37-2001:

$$N_t = \frac{365 \times [(1+\mathrm{r})^{\mathrm{n}} - 1]}{\mathrm{r}} \times \mathrm{A} \times \mathrm{D} \times \mathrm{F}$$

Where,
Nt = Cumulative number of standard axles (msa)
A = Initial traffic in the year of completion of construction (CVPD)
D = lane distribution factor
F = vehicle damage factor
n = pavement age (years)
r = traffic growth rate (%)

The traffic in the year of completion is estimated using following formula:

Step II Estimate the Composition of Pavement (IRC: 37-2012)

Step III Evaluation of Drainage Coefficients

The quality of drainage is in turn a function of the permeability of the subsurface materials, the cross fall and longitudinal slopes, the drainage distance (the length that Subsurface moisture must travel in order to exit the pavement structure), and the type of Drainage structures. The definitions of poor versus excellent drainage provided by AASHTO (1993) and as used in this study. These definitions are based on the time required for 50 percent of the free water to drain from the pavement section. The definitions do not consider the water retained by the effective porosity of the material (i.e., the water that will not drain under gravity.) Table 2 presents the AASHTO Relationship between Layer's Drainage ability and Subjective Drainage Quality Rating.

Table 2 AASHTO Relationship between Layer's Drainability and Subjective Drainage Quality Rating

S. No	Drainage Quality (DQ)	Water Removed From Layer Within
1	Excellent	2 hour
2	Good	1 day
3	Fair	1 week
4	Poor	1 month
5	Very poor	Water will not drain

The drainage coefficients are determined by considering the quality of drainage and the percent time that the pavement is exposed to moisture levels approaching saturation. Table 3 shows recommended ranges of drainage coefficients for a variety of drainage qualities and saturation times (AASHTO, 1993).

Table 3 Recommended d_i Values for Modifying Structural Layer Coefficients of Untreated Base and Sub-Base Materials in Flexible Pavements

Quality of Drainage	Percent Of Time Pavement Structure Is Exposed To Moisture Level Approaching Saturation			
	< 1%	1 to 5%	5 to 25 %	>25%
Excellent	1.40-1.35	1.35-1.30	1.30-1.20	1.20
Good	1.35-1.25	1.25-1.15	1.15-1.00	1.00
Fair	1.25-1.15	1.15-1.05	1.00-0.80	0.80
Poor	1.15-1.05	1.05-0.80	0.80-0.60	0.60
Very poor	1.05-0.95	0.95-0.75	0.75-0.40	0.40

Step IV Evaluation of Layer Strength Coefficients

The values of strength coefficients for different pavement layers are complied in table 4, Average values of layers coefficients for materials used in the AASTHO Road Test are as under (AASHTO 1986).

Table 4 Recommended values of Layer Coefficients a_i of Standard Materials From AASHTO Road Test (Rohde & Hartman, 1996).

S .No	Layer Type	Layer Coefficient

1	Asphaltic Concrete	0.44
2	Unbound Base Course	0.14
3	Sub-Base	0.11

Step V Computation of Modified Structural Number (SNC)

The modified structural number, SNC, is a means by which a pavement's structural capacity may be quantified. The following equation has been used to computation of SNC

$$SNC = 0.0394 \sum_{i}^{nlayer} a_i d_i h_i + SNSG$$

$SNSG = 3.51\log_{10}CBR - 0.85(\log_{10}CBR)^2 - 1.43$, for CBR ≥ 3

= 0, for CBR ≤ 3

Where SNC is the modified structural number

CBR is the California Bearing Ratio, in per cent

SNSG is the sub-grade strength contribution

a_i is the layer coefficient of the ith layer,

h_i is the thickness of the ith layer

d_i is the Drainage coefficient of the ith layer

Step VI Estimation of Initial Deflection (DEF0)

Initial deflection is calculated with the help of following models derived by CRRI for the Pavement performance study (PPS 1993) are similar to those used in HDM.

DEF=17.04*SNC (-2.62)

Where, DEF= Deflection,

SNC= Modified Structural Number (SNC)

It is represented that the PPS relationship given above are for granular base and sub-base courses and not for pavements with cemented courses.

Step VII Computation of Structural performance

The progression of the Deflection is calculated by using Deflection progression model (Reddy 1996). The Deflection progression models are function of initial Deflection (iDEF), age of the pavement and cumulative standard axels. The Deflection Progression models are given in table 5

Table 5 Deflection Progression Model

S. No.	iDEF Range(mm)	Model Form
1	0.44<iDEF<0.61	Dt=iDEF+0.07884[(Nt*Age)iDEF]
2	0.66<iDEF<0.80	Dt=iDEF+0.002exp[(iDEF*Nt)iDEF]+0.859(Age)
3	0.84<iDEF<1.05	Dt=IDEF +0.04513(expNt)0.45+0.0924(expAge)log iDEF
4	1.01<iDEF<1.25	Dt=iDEF+0.03658[exp(iDEF*Nt]0.5+0.19864(Age)0.26

5.2 A Framework for Quantification of Effect of Drainage Quality on Functional Performance of Pavement

The functional performance of the pavement is predicted in terms of roughness. The pavement roughness is the distortion of the pavement surface which contributes to an undesirable or uncomfortable ride. The road roughness (unevenness) may be related with the serviceability of the road, riding quality, and surface profile of the road. Roughness also affect the vehicles operating cost, inadequate care in finishing the road surface leads to heavy economic loss at the national level. A framework for quantification of effect of drainage quality on functional performance of pavement is presented in Fig. 2. The following major steps involved in computation of structural performance of the pavement

Step I Estimation of Design Traffic in Cumulative Standard Axles

Step II Estimate the Composition of Pavement (IRC: 37-2012)

Step III Evaluation of Drainage Coefficients

Step IV Evaluation of Layer Strength Coefficients

Step V Computation of Modified Structural Number (SNC)

Step VI Estimation of Initial Deflection (DEF0)

Step VII Evaluation of Initial Roughness (iUI)

The ministry of surface transport, governments of India recommends the following permissible limits for new constructions given in table 6

Table 6 Recommended Permissible Values for Indian Roads

S. No.	Type of surface	Permissible Value Of Roughness (mm/km)
1	Asphaltic Concrete	2500 mm/km
2	Premix Carpet	3500 mm/km
3	Surface Dressing	4500 mm/km
4	Semi Dense Carpet	3000 mm/km

Step VIII Computation of Functional Performance of Pavement

The Roughness of the pavement is predicted by using roughness progression model (Reddy 1996) roughness progression model is a function of initial roughness, deflection age of the pavement and cumulative standard axels.

$$UI_t = iUI\ [1+0.3012(N_t \times DEF_0)^{0.08\ Age}]$$

Where

UI_t = Roughness Index (mm/km)

iUI = Initial Roughness Index (mm/km)

Age = Age of the Pavement (years)

N_t = Cumulative Standard Axles (millions) in t years

DEF_0 = Deflection (mm)

6 Conclusions

Some of the important conclusions drawn from this study can be summarized as follows:

- Drainage is a key element in the design of pavement system. However inadequate drainage leads to major cause of pavement distress due to large amount of costly repairs or replacements long before reaching their design life.
- There is an urgent need to study the effect of drainage quality on pavement performance in India and quantify the benefit of the good drained system with respect to un-drained or poor drainage system.
- Effective drainage in roads is a critical requirement for ensuring stability and preventing the failure of pavement.
- This study presents a framework for evaluation of effect of drainage quality on structural performance of the pavement.
- This study also presents a framework for quantification of effect of drainage quality on functional performance of the pavement.
- It is expected that this study will useful to quantification of effect of drainage quality on pavement performance and improve the highway drainage system, thus to reduce the maintenance cost of highway pavement system and hence will be useful to preserve huge highway network in India

7 References

- *Rokade S. , Agarwal P. K Et al (2012); "Study On Drainage Related Performance Of Flexible Highway Pavements" International Journal of Advanced Engineering Technology vol 3 issue 1, January-March, 2012/334-337*
- *Gurjar J., (2011), " A Study On Effect of Drainage Quality on Pavement Performance" M. Tech Thesis completed in 2011 MANIT Bhopal.*
- *Veeraragavan, and G. Shailendra, (2010), "Research Need in Sub-Surface Drainage for Long Lasting Pavements," Highway Research Journal, January -June 2010, pp 1-23.*
- *Veeraragavan and G. Shailendra, (2010), "Quantification of Benefits of Improved Pavement Performance Due to Good Drainage," Journal, 71-1 January- March 2010, pp 77-99.*
- *Cedergren, H. R. (1998), Why all Important Pavements Should be Well Drained", Transportation Research Record, 1188, pp. 56-62.*
- *Carpenter, S.H, "Highway Subdrainage Design by Microcomputer (DAMP). Drainage Analysis and Modeling Programs." Publication No. FHWA-IP-90-012. Washington, D.C., 1990. 144 145*
- *Khanna, S.K., and Justo, C.E.G., (2001), "highway engineering", New Chand and Bros Publication, 8th edition, New Delhi.*
- *Kadyali, L.R., and Lal, N.B., (2006) , " Principle and Practices of Highway Engineering", Khanna Publication, 4th edition New Delhi...*
- *IRC: 37-2001"Guidelines For The Design Of Flexible Pavements" Indian Road Congress New Delhi 2001.*
- *IRC: SP 9-1972, "Road Drainage Practices around the World", Special Publication,Indian Roads Congress, New Delhi 1972.*
- *IRC: SP 42-1994, "Guidelines on Road Drainage", Special Publication, Indian Roads Congress, New Delhi 1994.*
- *IRC: SP 50-1999, "Guidelines on Urban drainage", Special Publication, Indian Roads Congress, New Delhi 1999.*

Table No. 1 Moisture Related Distresses in Flexible Pavement (Crapenter, 1981)

Type of Distresses	Distress Manifestation	Moisture Problem	Climate Problem	Material Problem	Load Associate	Structural Defects Begin In		
						Bituminous Layer	Base	Sub-Grade
Surface Defects	Abrasion	No	No	Aggregate	No	Yes	No	No
	Bleeding	No	Accounted by high temperature	Bitumen	No	Yes	No	No
	Rawing	No	No	Aggregate	Slightly	Yes	No	No
	Weathering	No	Humidity	Bitumen	No	Yes	No	No
Surface Deformation	Distortion	Excess Moisture	Frost Heave	Strength, Moisture	Yes	No	Yes	Yes
	Corrugation or Ripping	Slightly	Climatic and Suction relation	Unstable Mix	Yes	Yes	Yes	Yes
	Shoving	No	Suction Material	Unstable Mix	Yes	Yes	Yes	No
	Rutting	Excess in Granular layer	Suction Material	Compaction Properties	Yes	Yes	No	Yes
	Waves	Excess moisture	Suction Material	Expansive Clay	No	No	Yes	Yes
	Depression	Excess moisture	Suction Material	Settlement fill Material	Yes	No	No	Yes
	Potholes	Excess moisture	Frost Heave	Strength	Yes	No	No	Yes
Cracking	Alligator	Yes	Suction Material	Possible Mix Problem	Yes	Yes, Mix Problem	Yes	Yes
	Transverse	Yes	Suction Material	Thermal Properties	No	Yes Temp. Susceptibility	Yes	Yes
	Shrinkage	Yes	Suction Material	Moisture Sensitive	No	Yes , Hardening	Yes	Yes
	Slippage	Yes	No	Bond Loss	Yes	Yes	No	No
	Longitudinal	Yes	Spring Thaw	Strength Loss	Yes	Yes	Yes	Yes

International Journal of Engineering Research (ISSN : 2319-6890)
Volume No.2, Issue No. 3, pp : 259-265 01 July 2013

Fig: 1 A Framework for Quantification of Effect of Drainage Quality on Structural Performance of Pavement

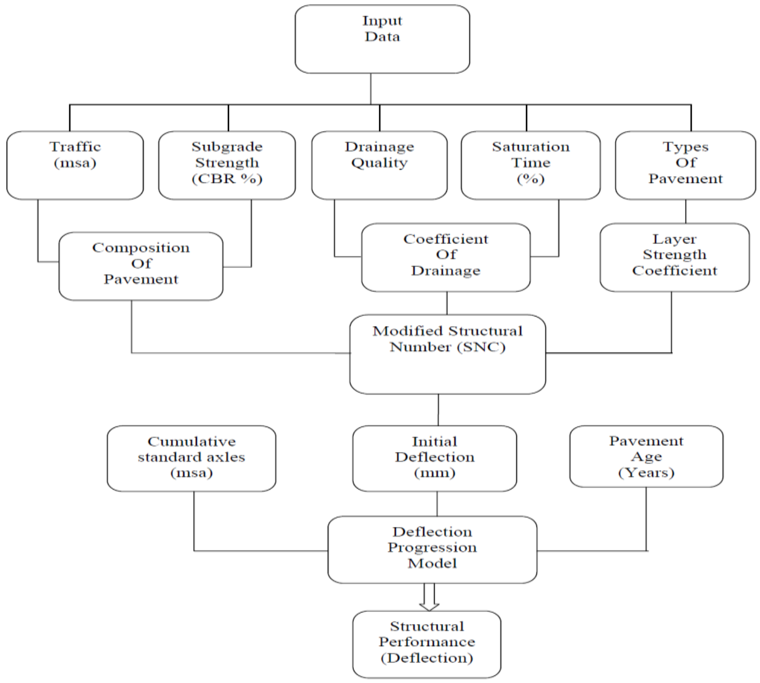

Fig: 2 A Framework for Quantification of Effect of Drainage Quality on Functional Performance of Pavement